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On The Role of Configuration Types and Surface Orientation on Ignition and Fire Spread in Array of Thin Solid Fuels

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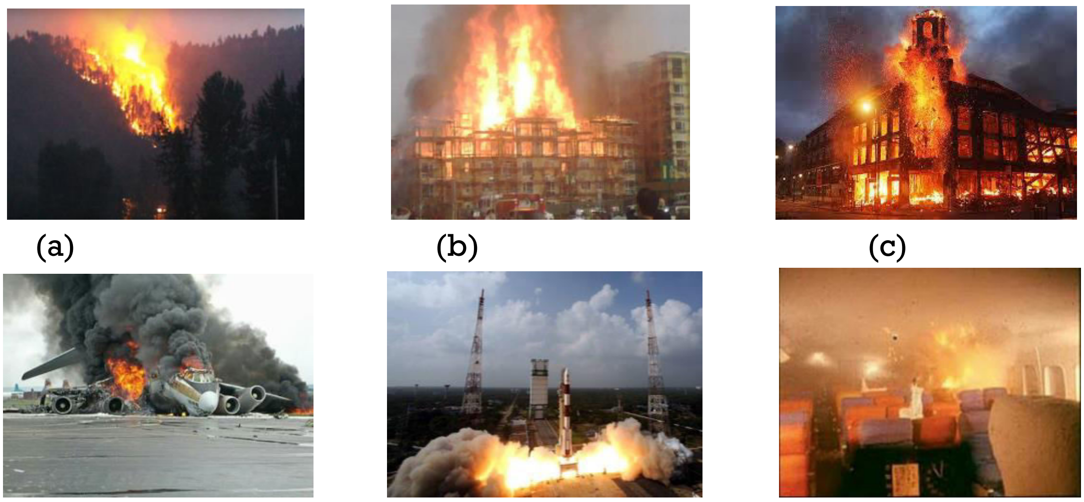
Abstract: With the increasing number of fire disasters in recent years and from the accompanying scientific development. It is imperative to test distinct approaches to develop enhance understanding of this heterogenous phenomenon to prevent future incidents and to minimize losses. The study presents a macroscopic qualitative approach to the assessment using central investigation parameters. With systematic experimentation, the fire propagation and self-ignition effect is explored. Varying linear configuration(s) incorporated with the slope effect is investigated and useful physical understanding is drawn to gain the true replication. Quintessential parameters like, nature of flame, classification of propagation effect, the flame height, assisting heat source and heat sink effect in view of self-ignition effect are observed. The results clearly show the large-scale fire propagation phenomenon to be highly heterogenous in nature. Unique singularities were observed with different cases which proposes better probability-based solution.

Introduction

Fire have been a constant foundation of enthused social progress. Fire application has resulted in splendid advancement in the fields of engineering, industrialization, practical, functional and operational systems. However, fires have had also been the biggest source of adversities the forms accidents in industries, forest(s), building(s), Aircraft and Rocket crashes, leading to immeasurable loss of human lives, nature, properties and every year enormous efforts are being taken on scientific research to achieve fire safety. National Fire Prevention Association (NFPA) data reports heavy fire losses in residential, industrial, educational institutions, and wildlife with 77% rise every year. One of the primary reasons is the marginal understanding of the about the fire ignition and spread. To resolve the issue, first, it is important to first understand the fire ignition and spread phenomenon. The study aims to offer in-depth understanding of fire spread. The work carries wide range of applications including storage, handling, stability, cost effectiveness and could be extensively used in combustion and propulsion systems, testing and upgradation like missile systems, power generation systems, practical, functional, scientific applications (refer figure 1).



(a) (b) (c)

(d) (e) (f)

Figure 1: Images of (a) forest fires, (b) building fires, (c) industrial fires, (d) aircraft fires, (e) rocket fires,
(f) compartment fires (* google.com).

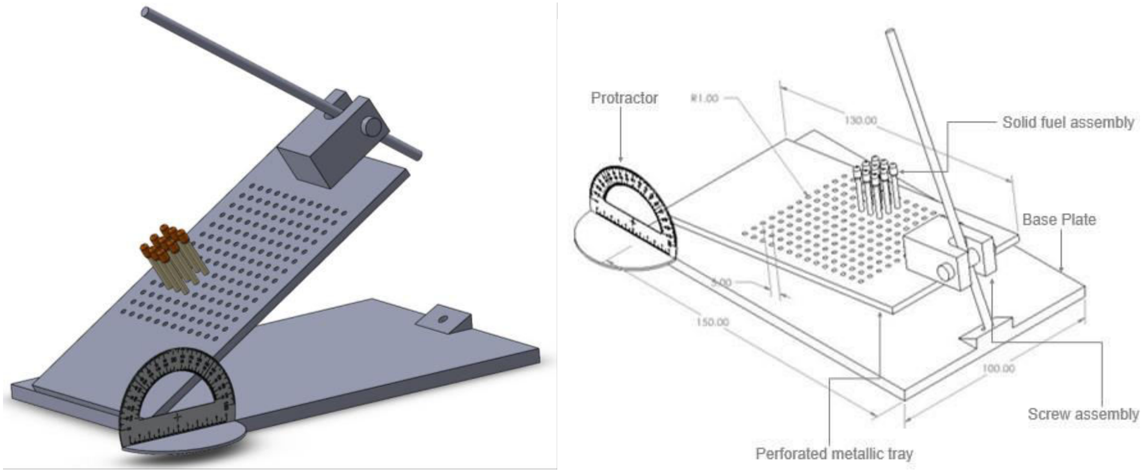
Following the classical work of (Egerton and Thabet, 1952) on the propagation phenomenon with burning speed measurement of slow flames and limits of combustion. The study detailed development of a technique to calculate burning speeds of combustible mixtures near the flammable limit using a burner. The process was applied to methane, propane, n-pentane, n-heptane, flames of velocities 5-10 cm/s and flame features were discussed. Results stated that the unburnt gas heating time by conduction is inadequate leading to radical diffusion from the fire front. (Rothermel and Anderson, 1966) investigated fire spreading mechanism to enhance knowledge of forest fires by burning pine needles, leaves, and rotten wood as the fuels. The laboratory research primarily aimed to understand the effect of moisture extent of the fuel and air velocity over it. The result produced useful physical insight into its cause fundamentally. The work also highlighted that for future experiments the geometric pattern-oriented experimentation leading to easy replication and will not be able to produce true replication of the phenomenon. (Vogel and Williams, 1970) investigated of flame propagation along horizontal arrays of vertically oriented matchsticks. Outcomes showed the compulsory situations for flame spread. The study offered, descriptions for the experimental remarks on the basis of model which used an ignition temperature and determined flame shapes. The remarkably good agreement between theory and experiment supported the argument that convective effects are of primary importance in flame propagation at matchstick size scales. (Rothermel, 1972) developed a mathematical model for estimation of spread rate for wide range of wildland fuels. The model was developed and being used as one of the imperative aspects in the NFDR (National Fire Danger Rating) system. The work was done using fuel arrays comprising of even size particles. The model required only inputs relating the environmental conditions in which it was expected to burn. Inputs included fuel loading, fuel depth, fuel particle heat content, fuel particle moisture and mineral content with wind velocity and slope of terrain. The results of the work introduced the concept of fuel models. These were used to predict fire spread and intensity. (Fernandez-Pello and Hirano, 1982) summarized the experimental studies on the science governing the flame spread over the combustible solids. The work advocated in practical situations fire spread in opposed flows occurs at near extinction with chemical kinetics playing a significant role. However, in the concurrent mode, forward heat transfer is the primary controlling mechanism. The study further detailed that chemical kinetics regulates the diffusion flame that causes the propagation development. (Jones, 1983) evaluated different fire models for further research in fire modeling. The work endeavoured to articulate each model in terms of similar variables. The one-room model with related physics was discoursed. The model was presumed to be rooted in a world of undeviating temperature and reference pressure with the conservation equations, the source and sink terms and contact of various objects in a single compartment fire. (Baines, 1990) worked on the different physical progressions which affect the fire spread rate on surface fuel beds including conduction, radiation from the flame and fuel bed, and convective heating influenced by wind. A new understanding of laboratory experiment(s) was specified, and balance between radiative heating from the flame and convective cooling of the fuel bed was recognized. (Weise and Biging, 1996) studied the implications of wind velocity and slope on fire spread rate and flame length. Experiments were carried out with vertical sticks fuel bed and coarse excelsior with mean fuel moisture content of 11% and 12%, respectively. The study combined varying slopes viz., negative, positive, none with varying wind velocities viz., heading, backing, none. The spread rates were measured with thermocouples and the flame length was assessed from video imagery. The results stated that spread rate of downslope heading fires exceeded that of no-wind/no-slope fires and augmented fuel moisture reduces spread rate and flame length. (Viegas, 1998) presented the diverse stages in the progress of fires and categorized the factors affecting them. The laboratory experiments on an inclined surface were carried out and the linkage between convection and radiation in the fire spread process was confirmed. Further, the results were detailed for wind-driven fires and an explanation for the fire front under slope or wind conditions was configured. The work highlighted problems of modelling the different fire behaviour regimes. The role of convection and radiation processes on fire propagation was considered. Furthermore, (Viegas, 2004) explored the fire propagation phenomenon with modulation of wind and slope effects on fire. The work presented the awareness of various fire spread directions and comprised effects of changing wind velocity and direction on point source flame fronts on fuel bed at 30°. (Sullivan, 2009) carried out a case study of advances in computational power in effort to model the behaviour of wildland fires. The study presented survey of all types of surface fire spread models developed during the period 1990–2007 of a physical or quasi-physical nature and mathematical analogues. The work directed that many models were extensions of models developed before 1990. (Gollner et. et al., 2012) investigated the fire propagation phenomenon in view of vertical matchstick array burning. Experimentation was done for vertical arrays of horizontal matchsticks, organized from one to five to examine the effect of the inter-spacing on rates of upward flame spread.

The results exhibited that the advancement of the ignition front varies linearly with time. The upward flame spread rates were found to increase intensely for low-spacings. Based on the observations, the impact of convective heating was offered to govern the propagation mechanism. (Alkhatib, 2014) evaluated machineries that have been used for forest fire detection of their techniques used. The work provided quintessential review of all the methods and deliberated examples of experiment results for better understanding. With thorough comparison, the study stated that each technique has its own advantages and disadvantages which entails the four methods. (Sharples, 2017) explored the issue of bushfire risk assessment. The study provided an assessment of the current standards and practices employed in bushfire risk assessment. The results of the review showed that the best practice in the development of bushfire management strategies suggestively under-estimate the risk of bushfire under extreme fire danger conditions. In recently, (Yuan et. al.,2020) investigated the self-heating phenomenon in porous fuels as a smouldering fire. In the study, a numerical model was built that connects the replication of thermal ignition and spread by adopting a two-step kinetic scheme. The model predictions were confirmed with hot plate experiments of coal in both flat and wedge configurations. The results thrusted that the hot spot instigated at the hot plate and spreads due to oxygen utilization. Appreciable scientific work had been carried out to deepen the understanding the fire propagation and self- heating effect as applicable to the large-scale fires. One aspect which is yet to be comprehensively investigated is to gain the true replication. Present work attempts an experimental lab scale study to establish the uniformity and outline of fire propagation phenomenon. Current study is primarily inspired by the necessity to improve understanding of fire spread phenomenon under varying conditions for better safety, reliability and suitable applications. The definite objectives of the investigation are:

a) To understand the qualitative nature of fire propagation and self-ignition effect for varying configuration(s) at different orientation(s).
b) To draw useful interrelations for large scale heterogenous fire spreading.
c) To identify the part of vital governing limitations.

Experimental Setup and Solution Methodology

A simple experimental setup (figure 2 (a & b)) was upraised for the study. The experimental setup consisted of a) metallic base plate, b) perforated metallic tray, c) protractor, d) screw assembly, e) solid fuel assembly as pilot fuel and an array of external energy source (labelled homemade match stick), f) stopwatch and g) shadowgraph (for optical visualisation). The design comprises of a metallic base plate attached to a movable perforated metallic tray with provisions for testing at different surface orientations.



(a) (b)

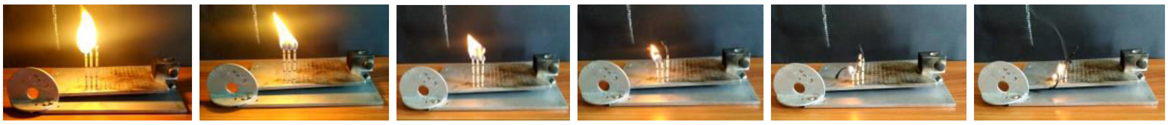
Figure 2: Schematic of (a) experimental setup representation, (b) component-wise characterization.

In an attempt to gain the true replication of the natural phenomenon, detailed analysis of pilot fuel ignition, self-ignition and propagation effect due to and on the external heat sources for varying configuration(s) was carried out. The experimental setup provides the provision for thoroughly investigating heterogeneous fires in presence of external heat source(s) and sink(s) along with the measurement of initial, average and instantaneous spread rate variation with sectional propagation in spatial and temporal domains. The predictions were corroborated with the conventional heat transfer theory besides the preceding research data and matches reasonably well. Different configuration(s) viz., unilateral, ‘Y’, ‘T’, ‘+’ for spatial (linear configuration(s)) with interspace distance of 0.5 cm and external energy source(s) as 2 for all directions were tested.

Experimentation is initiated with pilot fuel ignition and effect on external energy source(s) in the neighbourhood was observed. Entire experimentation was properly video graphed for maximum of 60 seconds and useful specifics were extracted. Noteworthy cases of completely, partially burnt and extinguished external energy sources, for different configuration were distinguished.
It is important to note that entire experimentation was carried out in normal and controlled conditions with oxygen concentration of 21% and the data presented represents repeatability and reproducibility of Third Order.

Result and Discussions

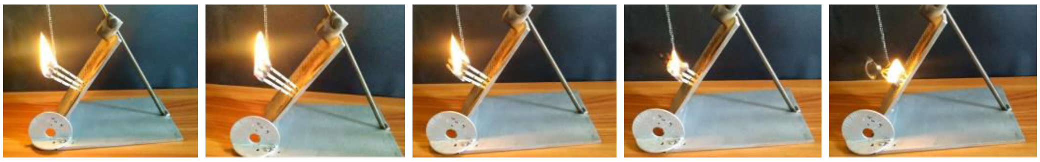
In practical scenario, the ignition source is always surrounded by the external heat sources (provides energy, enhances maximum temperature) and external heat sinks (takes energy of ignition source and results in suppression). Thus, in order to gain the true replication, systematic experimentation was carried out to observe the occurrence and variation of flame propagation behavior and the self-ignition effect in form of heterogeneous energy transition. The fire behaviour was observed in terms of parameters viz., modulation in ignition, flame shape and size, sustenance with time and the surface orientation. The role of surface orientation was tested on propagation and self-ignition effect with variation in surface orientation for cases of 0°, 45°, and 90° for different linear configurations.



(a) (b) (c) (d) (e) (f)

Figure 3: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for unilateral configuration (0°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec, (f) 50 sec.

Figure 3 (a-f) shows the fire propagation and self-ignition effect for unilateral configuration at 0°. Looking at the images one can note the abrupt propagation with self-ignition of external energy source(s) resulting in a single large merged flame (figure 3(a)). With respect to time, the intensity of flame suddenly drops which directly reflects on the propagation phenomenon (refer figure 3(b)). Furthermore, the coupled flame dissociates and gradually converts into weaker singular flame with time (figure 3(d-e-f)). The case represents partially burning where propagation and self-ignition effect and was observed however, it was not strong enough to burn the entire configuration.



(a) (b) (c) (d) (e)

Figure 4: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for unilateral configuration (45°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec.

Significant changes were observed with further variation in surface orientation to 45° (figure 4 (a-f)). Rapid propagation and self-ignition effect resulting in a single merged flame (figure 4(a)) was noted. With respect to time, marginal increase in flame intensity was observed which indicates cohesive propagation effects (refer figure 4(b-c)). It was exciting to note that the flame remains single, merged and resulted in ordered spread (figure 4(d-e-f)). One can note that, the merged flame at 0° represents the strongest of all merged flames. The case of 45° surface orientation characterizes total burning where propagation and self-ignition effect and were strongly observed and burnt the entire configuration thoroughly.

(a) (b) (c) (d)

Figure 5: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for unilateral configuration (90°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec.

Surface orientation of 90° represents extreme case of abrupt fire propagation and self-ignition effect merging into a single, large flame (figure 5(a)). The vertical surface orientation represents highest flame height and strongest coupled flame. With time, increase in flame intensity was observed which indicates dominating propagation effects (figure 5(b-c)). The flame remains single, merged and well patterned propagation (figure 5(d)). The case of 90° surface orientation also represents total burning case. It is interesting to note that, the surface orientation strikes an important role in providing stability to the external energy sources with self-ignition and propagation effect which grows till vertical.

(a) (b) (c) (d) (e)

(f)

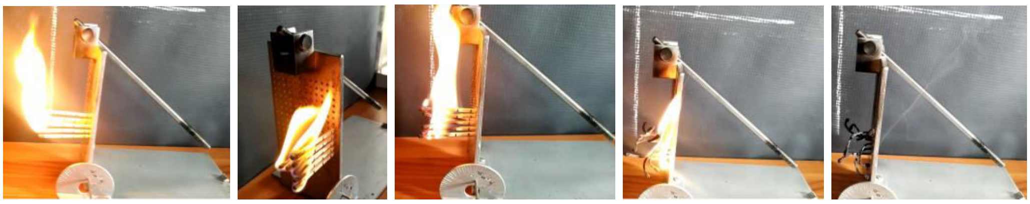
Figure 6: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for 'T' configuration (0°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec, (f) 50 sec.

Next, the behavior of fire propagation was observed upon 'T' configuration. The behavior of self-ignition and propagation effect is investigated with varying surface orientation and duly compared with 'Unilateral' configuration under similar conditions. Figure 6 (a-f) highlights the self-ignition and fire propagation effect for 'T' configuration at 0° (horizontal). With ignition of pilot fuel (figure 6(a)), rapid self-ignition of external energy source(s) occurs resulting in a single merged flame (figure 6(c)). With time, the coupled flame intensity drops (figure 6(d)) leading to flame extinction and emerging as a flame extinction case (figure 6(e-f)). Similar to the 'Unilateral' configuration, 'T' configuration reports rapid self-ignition and consequently drop in flame intensity with time. However, the flame extinction effect is more adverse in 'T' configuration than in the 'Unliteral' configuration which reports partially burnt case.

(a) (b) (c) (d) (e)

Figure 7: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for 'T' configuration (45°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec.

To understand the heterogenous behavior, the surface orientation was further varied to 45°, and figure (7(a-e)) shows the self-ignition and fire propagation nature with time. In comparison to the single, merged, well pattered flame with gradual drop in flame intensity representing totally burnt case, 'T' configuration signifies sudden emergence of single, merged flame with steady drop in flame intensity till significant time (figure 7(a-c)). After selected time (here, 30 sec), the drop in flame intensity rises however flame remains single and merged (figure (7(d)). It is interesting to note that, phenomenon of sudden re-emergence of large singular flames was observed with flame height higher than initial steady cases. The re-emergence leads to abrupt propagation and total burning of entire configuration (figure 7(e)). The case of 45° 'T' configuration details the fastest fire propagation effect noted.



(a) (b) (c) (d) (e)

Figure 8: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for 'T' configuration (90°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec.

Vertical orientation case often represents concurrent flame spread resulting in stronger self-ignition and propagation effects. 'Unilateral' configuration detailed sudden merging, bigger flame and fast propagation and 'T' configuration matches the process (figure 8(a-e)). The pilot fuel ignition results in immensely stronger self-ignition effect with a single, merged, larger flame (figure 8(a)). The flame intensity drops with time (figure 8(b)) but, results in strong re-emergence of merged, coupled flame with greater flame height than other configuration and orientation (figure 8(c)). It is interesting to note that, with time the flame intensity drops again slightly without significantly affecting the flame structure and finally completely burns the entire configuration (figure 8(d-e)). In comparison to other surface orientations, 90° dictates strong buoyant convection effect resulting in a strong, merged flame without any sudden re-emergence or extinction. In comparison to 'Unilateral' configuration, the 'T' configuration dictates stronger propagation characteristics. It is important to note that, the noted changes in fire behavior do not adhere to surface orientation and configuration. Different configurations at same surface orientation may respond to similar behavior and similar configuration at varying orientation may result in distinct fire behavior cases which details the coupled role of both configurations and surface orientation.

(a) (b) (c) (d) (e) (f)

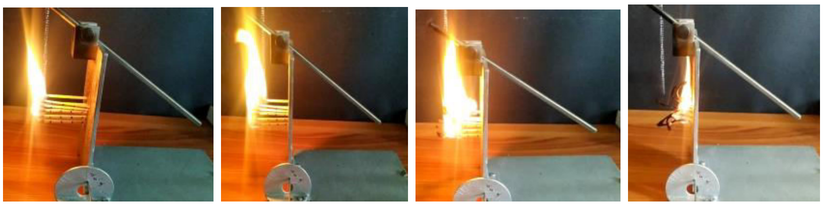
Figure 9: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for 'Y' configuration (0°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec, (f) 50 sec.

Trilateral or 'Y' configuration responds similar to the unilateral and 'T' highlighting the heterogenous fire spread behavior. Figure 9 (a-f) shows the pictorial representations of 'Y' configuration for horizontal surface orientation (0°) with time. Looking at the images one can note that, the self-ignition and fire propagation effect responds in a distinct pattern. Post pilot fuel ignition, self-ignition effect results in a single merged flame (figure 9(a-b)). With time, the flame starts to disintegrate into localized singular flames (figure 9(c-e)). Under similar surface orientation conditions, 'unilateral' configuration results in well patterned single merged flame with slow propagation and partial burning whereas 'T' configuration shows enhanced fire propagation with single merged flame resulting in fire extinction. The flame intensity is modulated with sudden increase and decrease resulting in formation of localized flame zones which sustains till complete burning.

(a) (b) (c) (d) (e) (f)

Figure 10: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for 'Y' configuration (45°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec, (f) 50 sec.

Further, at 45° surface orientation, partial self-ignition effect was noted with formation of single merged flame (figure 10(a)) and converges in a confined zone. With time, flame intensity first rises resulting in larger flame height (figure 10(b)) followed by the sudden drop (figure 10(c)) which drops suddenly (figure 10(d)). The energy transfer undergoes transition with formation of localized singular flames within the confined zone (figure 10(e)). It is interesting to note that, post zonal burning, the flame extends to the unburnt regions with final resulting in a complete burning case (figure 10(f)). Under similar surface orientation conditions, 'unilateral' configuration results in a well patterned single merged flame with slow propagation resulting in a complete burning case however 'T' configuration shows abrupt self-ignition with larger merged flame and faster flame propagation and sudden dissociation in magnified localized flames ending with partial burning. The 45° case shows diverse nature of flame propagation with distinct changes in flame intensity within a localized zone and picking up in remaining unburnt zone in the end.



(a) (b) c) (d)

Figure 11: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for 'Y' configuration (90°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec.

Next, we look at special vertical surface orientation (90°). Figure 11(a-d) highlights the self-ignition and flame propagation behavior. Looking at the images one can note that, post pilot fuel ignition the upward spread intensifies in a larger merged flame (figure 11(a)). With time, the flame intensity rises and gains consistency resulting in faster complete burning case (figure 11(b-d)). Under similar surface orientation conditions, 'unilateral' configuration displays slow start of self-ignition and propagation effect which suddenly rises resulting in abrupt complete burning case with lower flame height however 'T' configuration retorts with rapid self-ignition in form of maximum single merged flame height with instable flame intensity. The 90° case shows the controlled upward spread effect with sudden rise to larger single flame which sustains with time with minimum fluctuations.

(a) (b) (c) (d) (e) (f)

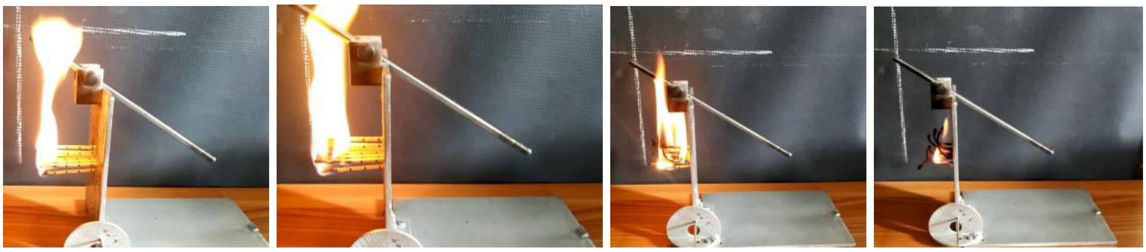
Figure 12: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for '+' configuration (0°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec, (f) 50 sec.

To corroborate the heterogenous nature of self-ignition and fire propagation effect, systematic observation of '+' configuration under similar conditions was carried out. Figure 12(a-f) shows the fire behaviour with time for horizontal surface orientation (0°). '+' configuration represents rapid self-ignition and fire propagation with uneven energy interaction resulting in maximum flame height (figure 12(a)). With time, the single merged flame regains stability and flame intensity drops with height (figure 12(b-c)). Furthermore, the flame starts shrinking keeping outermost external energy source(s) unburnt (figure 12(d)) with rapid drop in intensity leading to extinction (figure 12(e-f)) thus making it a case of partial burning. In comparison with other configurations under similar conditions, 'unilateral' configuration shows higher stability post pilot fuel ignition with formation of single merged flame in which flame intensity drops with time leading to partial burning case. 'T' configuration responds with lower energy interaction in the form of single merged flame which gains intensity with time and ending similar to 'unilateral' in partial burning case. 'Y' configuration represents the dissociation of single merged flame into localized flames however resulting in complete burning case. The horizontal surface orientation case details instability in self-ignition and propagation effect with turbulent rise and sudden drop in flame intensity.

(a) (b) (c) (d) (e)

Figure 13: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for '+' configuration (45°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec, (e) 40 sec.

At 45° surface orientation, unlike other surface orientation cases, '+' configuration results in abrupt self-ignition and propagation effect with single merged flame of maximum height (figure 13(a)). With time, the flame intensity fluctuates with sudden drop and rise as noted with flame height resulting in complete burning case (figure 13(b-d)). It was stimulating to note that the flame remains single and was found merged with no signs of dissociation. In comparison with other configurations under similar conditions, 'unilateral' configuration shows a slow, steady and single merged flame with complete burning whereas 'T' configuration presents intermittent self-ignition and propagation effect besides re-emergence of strong localized flames ending in complete burning however 'Y' configuration specifies the confined self-ignition and propagation effect with large single merged flame resulting in complete burning case. The 45° surface orientation case indicates strong self-ignition effect with gradual drop in flame intensity to a critical limit.



(a) (b) (c) (d)

Figure 14: Pictorial representation of temporal variation of self-induced ignition and propagation phenomenon for '+' configuration (90°) (a) 5 sec, (b) 10 sec, (c) 20 sec, (d) 30 sec.

For the case of vertical surface orientation (90°), '+' configuration qualitatively corroborates with other configuration(s) in rapid self-ignition, fire propagation and faster burning leading to complete burning phenomenon. Figure 14(a-d) shows the behavior of fire propagation along with self-ignition effect. With pilot fuel ignition, upward fire spread depicts rapid self-ignition as a single merged flame which is uninhabited (figure 14(a)). With time, the unsteadiness in flame grows which results in faster propagation and increase in flame height (figure 14(b)). Gradually flame intensity drops reasonably however flame remains single and merged (figure 14(c)) thus leading to complete burning case (figure 14(d)). In comparison with other configurations under similar conditions, 'unilateral' configuration shows rapid self-ignition, and propagation which sustains. 'T' configuration represents abrupt unsteadiness in fire behavior which modulates with time. 'Y' configuration specifies usual rapid, consistent upward spread with rapid self-ignition and fire propagation leading to faster complete burning. The 90° surface orientation case details the instability and stability phenomenon interrelation in fire propagation with time. The effect highlights the instability with uneven energy transfer however the fire regains stability which further leads to instability. It is interesting to note that, instability in a natural phenomenon leads to stability and vice versa.

Conclusions

Systematic experimental investigation and qualitative analysis of the fire spread singularity was carried to understand the heterogenous behavior of fires in presence of external heat source(s). The study was motivated to gain true replication of the natural phenomenon, in different linear configuration(s). The primary aspect(s) observed was the self-ignition and fire propagation effect for different linear configuration(s) viz., unilateral, 'T', 'Y', '+' with pilot fuel ignition. Important information was drawn with parameters like flame structure, propagation pattern, changes with time. Based on the results obtained through experimentation and following graphical analysis, following major conclusions can be drawn:

1) The investigation validates that in large scale fires, presence of external energy source(s) always exists in the form of heat source and heat sink effects.
2) Different linear configuration(s) tested with pilot fuel ignition corroborates the heterogenous fire behaviour under similar conditions as with self-ignition and propagation effect.
3) Surface orientation plays a quintessential role in altering the fire behavior under different conditions resulting in cases of partial, complete burning and extinction. The effect can be noted in form of providing stability to the external energy source(s), rapid self-ignition and subsequently drop in flame intensity with time, dual nature of flame merging and segregation, modulated flame intensity with sudden increase and decrease resulting in formation of localized flame zones, instability with unsteadiness and re-emergence of steady fire behavior with time.

4) Different configurations under similar surface orientation conditions depicts heterogeneity by responding in similar behavior and in distinct fire behavior which details the coupled role of both configurations and surface orientation.
5) The horizontal surface orientation largely depicts cases with controlled self-ignition and fire propagation effect whereas, the vertical surface orientation case details the instability and stability phenomenon interrelation in fire propagation with time.
6) The reason for heterogenous nature may be attributed to the uneven energy transfer that is a result of self-ignition and propagation effect post pilot fuel ignition. As a uniformity, this outcomes in a single, merged flame for all configuration(s). The effect details the flame instability and mode of regaining stability with uneven energy transfer which further leads to instability marking that, instability in a natural phenomenon leads to stability and vice versa.

7) **Applications of the work:** To provide closed form solution to the fire safety related issues, it is imperative to understand the behavior and governing mechanism of the phenomenon. The physical insight from the present study can be very useful in understanding the nature of large-scale fires viz., forest fires, compartment fires, building fires, propulsive fires. This knowledge can be utilized to increase the control time, devise new fire safety equipments, in testing, validation and designing of existing system and engineering structures.

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